GEXCON

使用 FLACS 在 FPSO/FLNG 中进行火灾和爆炸模拟
Fire and Explosion simulation with FLACS in FPSO/FLNG

Gexcon Xie Bin

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Gexcon Introduction

GEXCON

在复杂扩散、爆炸和火灾模拟领域全球顶尖的安全风险管理公司(整合先进咨询、尖端软件和全面测试服务)

An integrated approach using advanced consulting, leading-edge software, and comprehensive testing services.

软件

- 提供各种安全软件，用于各种物质的扩散、爆炸和火灾模拟
  Gexcon offers a wide variety of safety software for dispersion, explosion and fire modelling of various substances
- 这些工具包括后果模拟工具、定量风险评估 (QRA) 工具和事故前规划
  These include consequence modelling tools, Quantitative Risk Assessment (QRA) tools, and pre-incident planning
- 软件工具：FLACS、EFFECTS、RISKCURVES
  X-Suite software tools: FLACS, EFFECTS, RISKCURVES
- 壳牌公司(FRED、Shepherd、PIPA)软件工具的官方经销商
  Official distributor of Shell software tools (FRED、Shepherd、PIPA)

火灾爆炸测试

- 进行测试、认证和商业研究
  Gexcon carries out testing, certification, and commercial research
- 用于大规模和小规模测试的设备
  Facilities for large-scale and small-scale testing
- 提供多种测试选项;标准化 vs 专业化
  Provides various options of testing; standardised vs specialised
- 第三方设备认证
  Certification of third-party equipment
- 测试数据用于为软件模型优化并验证软件模型准确性
  Testing data is used to compile knowledge for X-Suite and validate the software tools

咨询服务

- 几十年来，Gexcon 通过开展安全研究，在安全和风险管理领域积累了独特的专业知识
  Gexcon has built up unique expertise in the field of safety and risk management by conducting safety studies and research for decades
- 在众多国家/地区设有办事处
  Currently with local presence in market leading regions
- Gexcon参与了全球一些重大的事故调查
  The consultants are involved in some of the world’s largest accident investigations
- 融合软件和试验结果
  The intersection of knowledge through software and testing

用于安全和风险管理的一体化解决方案

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All-in one solution for safety and risk management

EFFECTS 后果模拟
EFFECTS Integral Consequence Modelling

- EFFECTS 是一款先进的用户界面友好的软件，用于分析危险化学品意外泄漏的后果。
  EFFECTS is an advanced user-friendly software to analyse the consequences of the accidental release of dangerous chemicals.
- 它计算火灾产生的热辐射、爆炸产生的超压以及扩散气云产生的毒性浓度/剂量。
  It calculates heat radiation from fires, overpressure from explosion and toxic concentrations/dose from dispersing clouds.

FLACS CFD 后果模拟
FLACS CFD Consequence Modelling

- FLACS 是一款功能强大且全面的行业领先 CFD 软件，用于模拟危险化学品的扩散、火灾和爆炸。
  FLACS is a powerful and comprehensive industry-leading CFD software to simulate the dispersion of hazardous materials, fire and explosion.
- 它具有 3D 可视化功能，包括真实几何模型影响和实施缓解措施的效果。
  It features 3D visualisations that include effects of real geometries, includes the effect of implementing mitigation measures.

RISKCURVES QRA/风险模拟
RISKCURVES QRA*/ Risk Modelling

- RISKCURVES 是一款先进的软件，用于执行 QRA，用于评估在流程设施中存储和运输危险物质的风险。
  RISKCURVES is an advanced software to perform QRAs for storing and transporting dangerous goods in process facilities.
- 它能计算特定位置的个人风险等值线，即每年个人风险 （IRPA），FN 曲线、社会风险地图和风险排名报告。
  It presents location-specific individual risk contours, individual risk per annum (IRPA). fN curves, societal risk maps, and risk ranking reports.

*Quantitative Risk Assessment

可靠的计算结果 Reliable calculation results

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坚实的科学背景 Solid scientific background

- EFFECTS & RISKCURVES 基于 TNO* 彩色书籍（ Coloured Books ）

- 紫皮书 PURPLE BOOK
  定量风险分析指南 (Guidelines for quantitative risk assessment)
- 红皮书 RED BOOK
  概率确定及计算方法 (Methods for determining and processing probabilities)
- 黄皮书 YELLOW BOOK
  有害物质泄漏的物理后果计算方法
  (Methods for the calculation of Physical Effects Due to releases of hazardous materials (liquids and gases))
- 绿皮书 GREEN BOOK
  有害物质泄漏对人或物体造成的可能损伤的计算方法
  (Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials)

*TNO - 荷兰应用科学研究组织。EFFECTS & RISKCURVES 于 80 年代首次作为商业软件发布。

*TNO - Netherlands Organisation for Applied Scientific Research. EFFECTS & RISKCURVES was first released as commercial software in the 1980s.

FLACS模拟结果和爆炸试验对比验证

Comparison and verification of FLACS simulation results and explosion tests

1993-1996 50 methane explosion experiments with varying congestion, confinement and ignition location (JIP report 1995)

1993-1994 Extensive grid dependency study for explosion modeling (JIP report 1994)

1994-1995 Blast propagation in the far field, 10 tests (JIP report 1995)

1993-1996 >50 experiments with water deluge Gexcon and BG experiments (JIP report 1996)

1994-1997 ~50 BFETS 2 & 3A large-scale explosion tests, variation in ignition point, congestion and more (JIP report 1998)

1994-1998 Ventilation studies vs wind measurements at various oil platforms (e.g. Oseberg-C, Beryl-B, Nelson)

1997-1999 MOGELEG, Gexcon labscale experiments on the effect of nitrogen and CO2 dilution (JIP report 1998)

1996-1999 SMEDIS, EU project on evaluation of dispersion modeling (JIP report 1999)

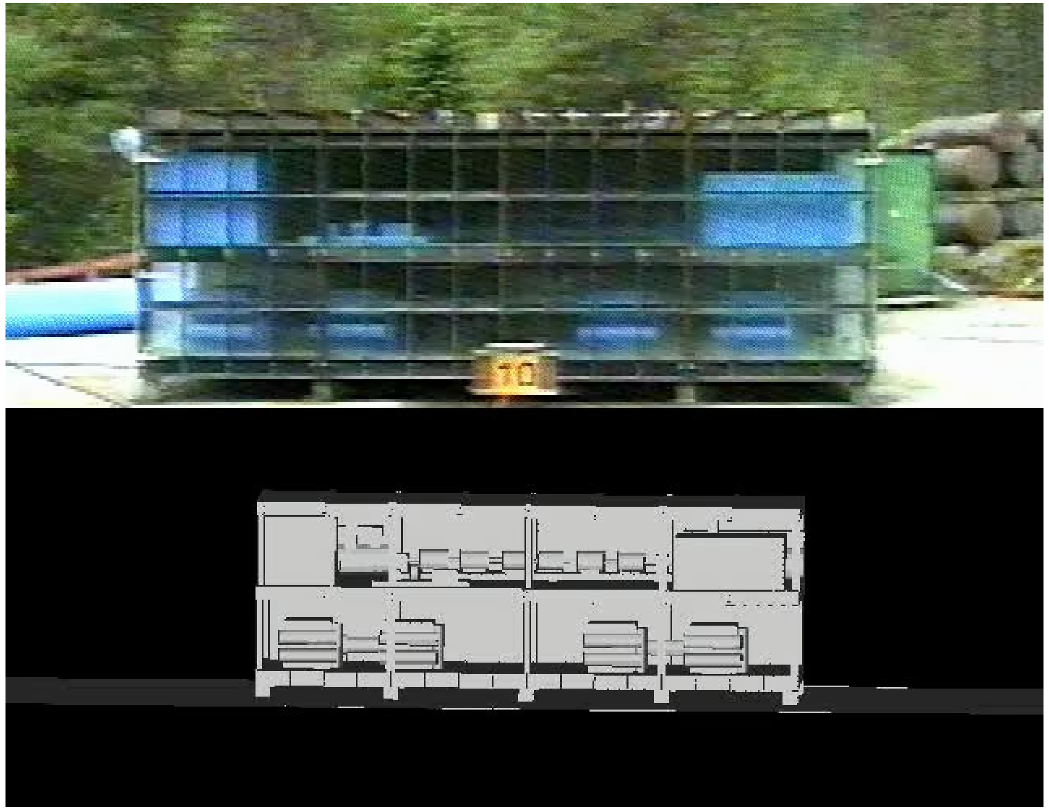
1998-2000 Gexcon 50m3 and BFETS 3B large scale dispersion and explosion tests (JIP report 2001)

2001-2004 100 lab-scale (Gexcon)+ 25 large-scale (Sandia) hydrogen experiments (JIP report + ICHS-paper 2005)

2002-2004 Validation against Kit Fox, MUST and Prairie Grass atmospheric dispersion tests (Hanna Atm Env 2004)

2005-2008 15 large scale LNG dispersion experiments Burro&Coyote, Maplin Sands (Hansen, LPS 2007)

2004-2009 Various HySafe hydrogen dispersion and explosion studies (Several papers by Hansen & Middha)



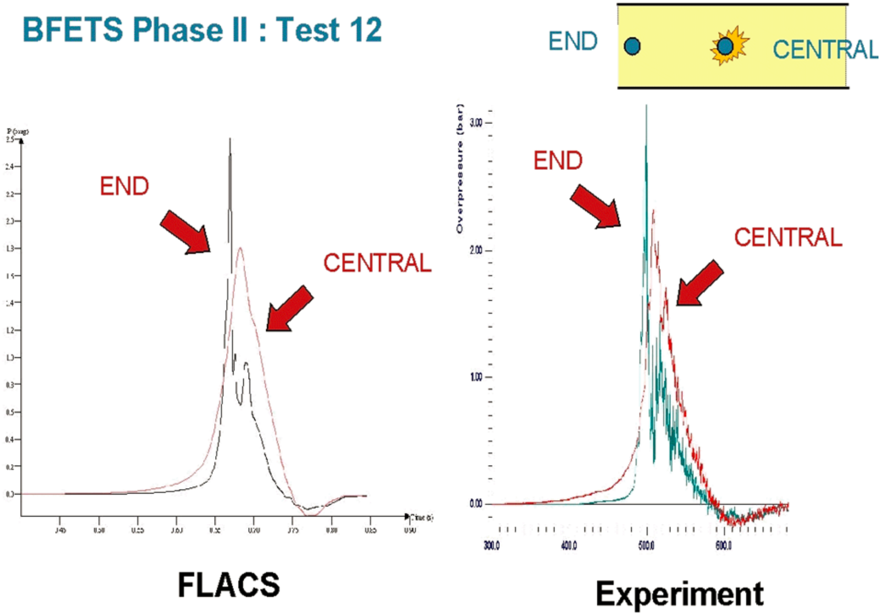
独立预测项目 (Blind prediction activities):

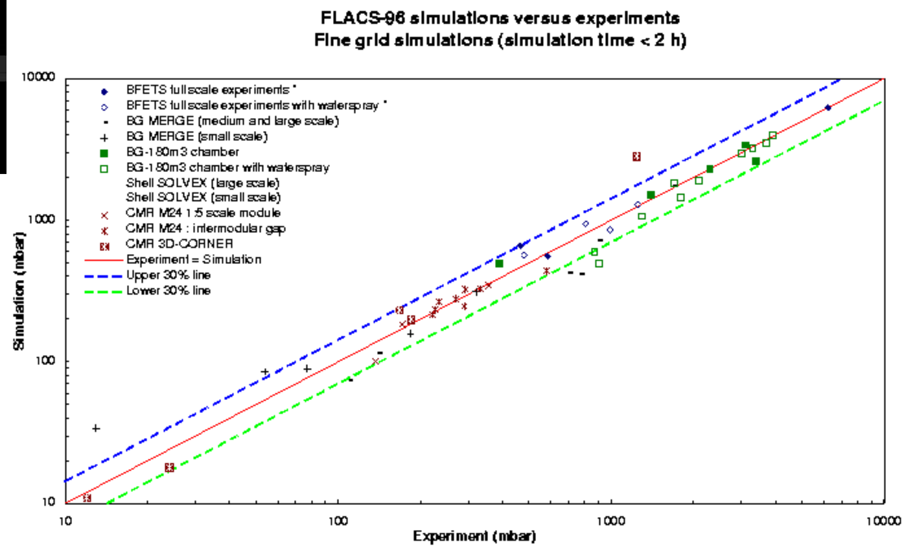
H2 dispersion INERIS 6C (18 HySafe partners)

Shell H2workshop ignited jets (HySafe)

Dispersion scenarios at Manhattan (PNNL)

Coal mine methane explosion tests (NIOSH)





大尺度试验与模拟结果对比

Comparison of large-scale test and simulation results

no. 27 试验

Test No. 27

- 右边的实验是一个20英尺长的容器，里面装有21％的氢气。

The experiment on the right is a 20-foot-long container filled with 21% hydrogen gas.

Funded under

SOCIETAL CHALLENGES - Secure, clean and efficient energy

Total cost

€ 1 511 780,00

EU contribution

€ 1 494 780,00

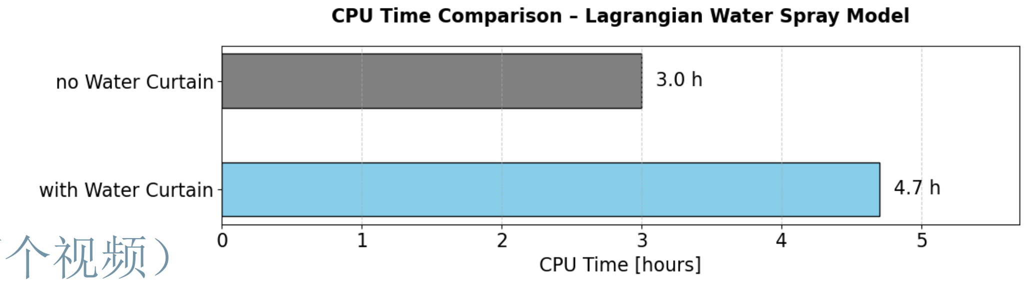
Coordinated by

GEXCON AS

Norway

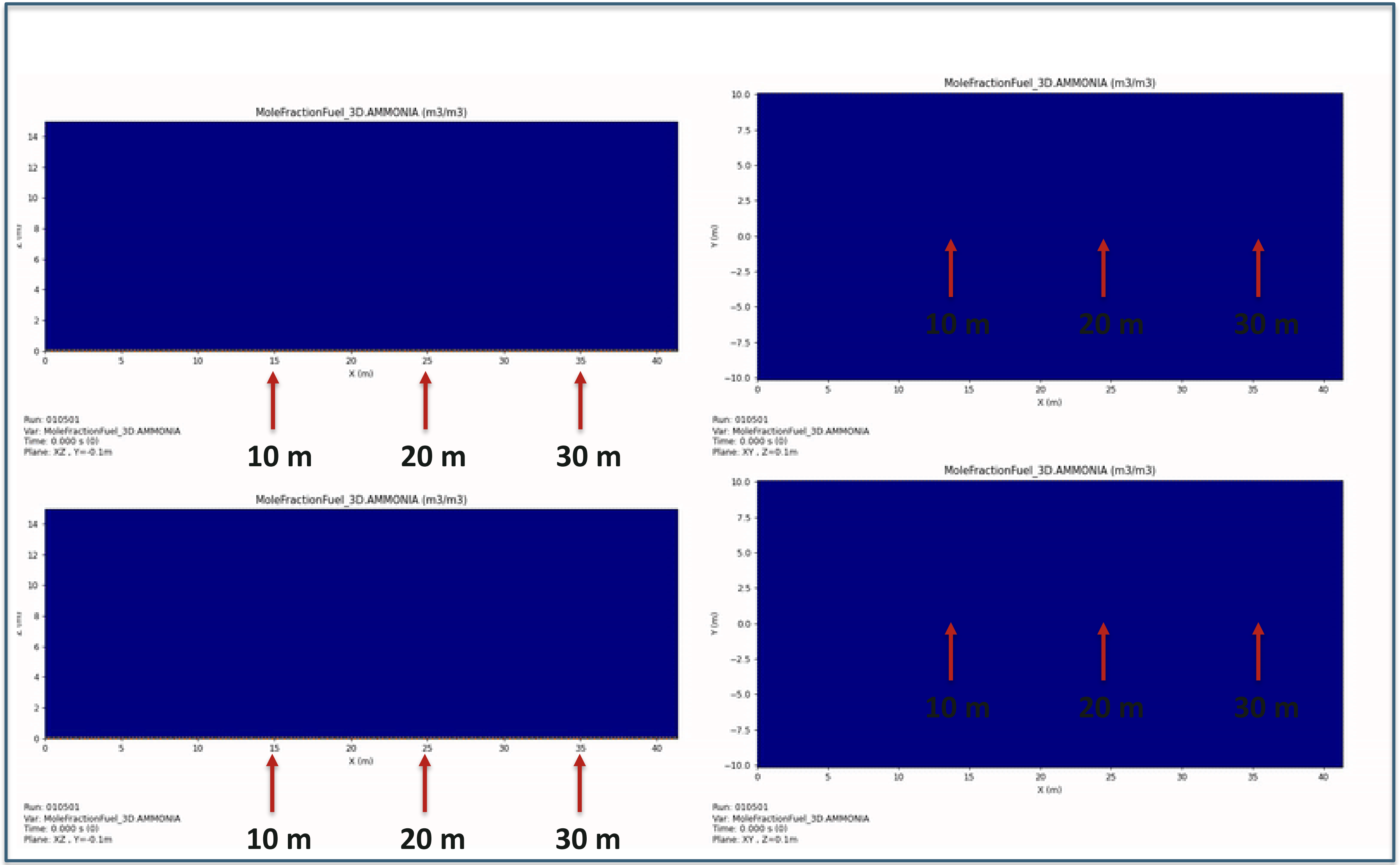
水幕-吸收

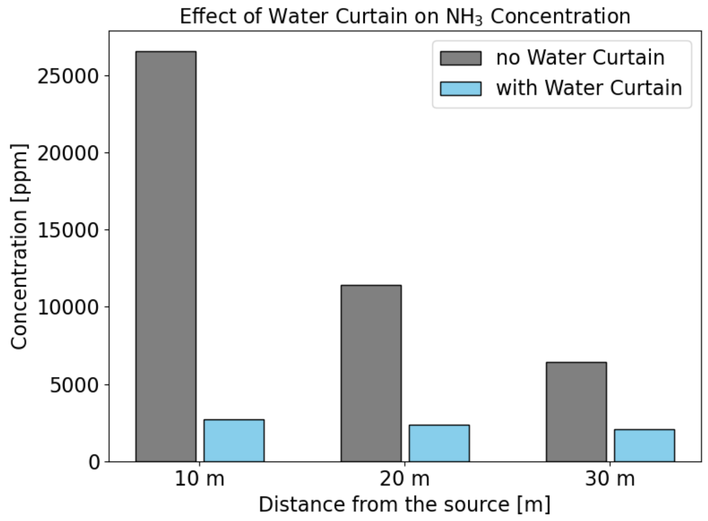
Water Curtain- absorption

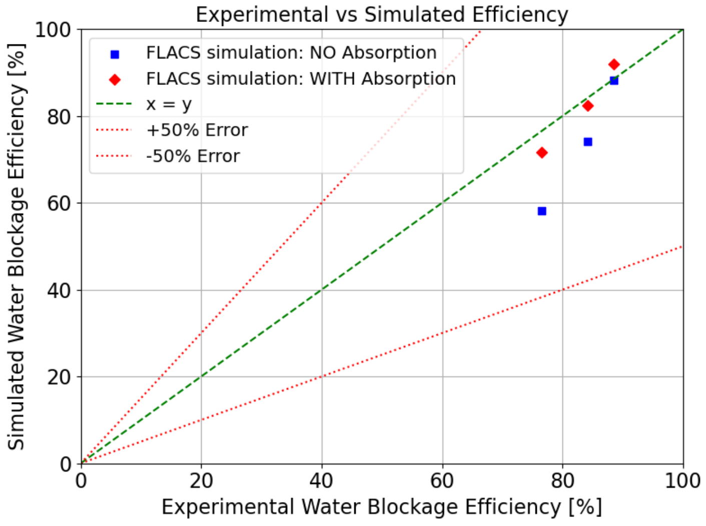


氨气扩散没有水幕（上面两个视频）和有水幕（下面两个视频）

Ammonia dispersion without water curtain (two videos above) and with water curtain (two videos below)







Experiment: Dandrieux et al. J. Loss Prev. Process Ind. 14 (2001) 349–355

全球首座10万吨级深水半潜式生产储油平台“深海一号”

The world's first 100,000-ton deepwater semi-submersible production storage and offloading platform"Deep Sea No.1"

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- 2021年1月18日在山东烟台交付启航，它的成功交付标志着我国深水油气田开发能力和深水海洋工程装备建造水平取得重大突破，对提升我国海洋资源开发能力、保障国家能源安全和支撑海洋强国战略具有重要意义。
  It was delivered and set sail in Yantai, Shandong on January 18, 2021. Its successful delivery marks a major breakthrough in my country's deepwater oil and gas field development capabilities and deepwater marine engineering equipment construction level. It is of great significance to enhancing my country’s marine resource development capabilities, ensuring national energy security and supporting the strategy of building a strong maritime nation.

- 该项目在建造阶段实现3项世界级创新，即世界首创立柱储油、世界最大跨度半潜平台桁架式组块技术、世界首次在陆地上采用船坞内湿式半坐墩大合拢技术，同时运用了包括1500米级水深聚酯缆锚泊系统设计与安装、30年不进坞维修的浮体结构疲劳设计与检测等在内的13项国内首创技术，攻克了10多项业界难题。
  During the construction phase, the project achieved three world-class innovations, namely the world's first pillar oil storage, the world's largest span semi-submersible platform truss module technology, and the world's first use of wet semi-pier large-scale closure technology in the dock on land. At the same time, it used 13 domestically pioneering technologies, including the design and installation of a 1,500-meter-deep polyester cable mooring system, and the fatigue design and testing of floating structures that do not require docking for maintenance for 30 years, and overcame more than 10 industry challenges.

02 二维经验公式模型和三维FLACS比较

Comparison between 2D empirical formula model and 3D FLACS

几何模型影响

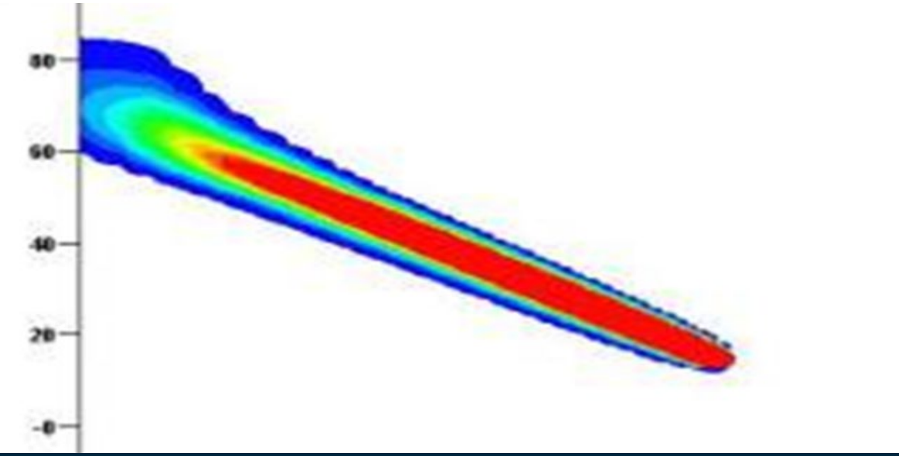
Influence of geometry

墙壁对气体高速射流的遮挡作用

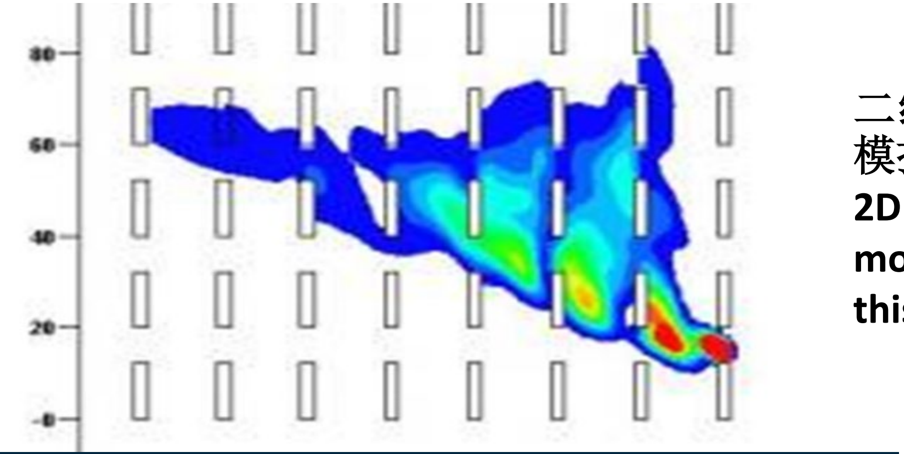
Shielding effect of the wall on the high-velocity gas jet

自由射流 Free jet

阻塞的射流 Impinging jet



无障碍 No obstacles



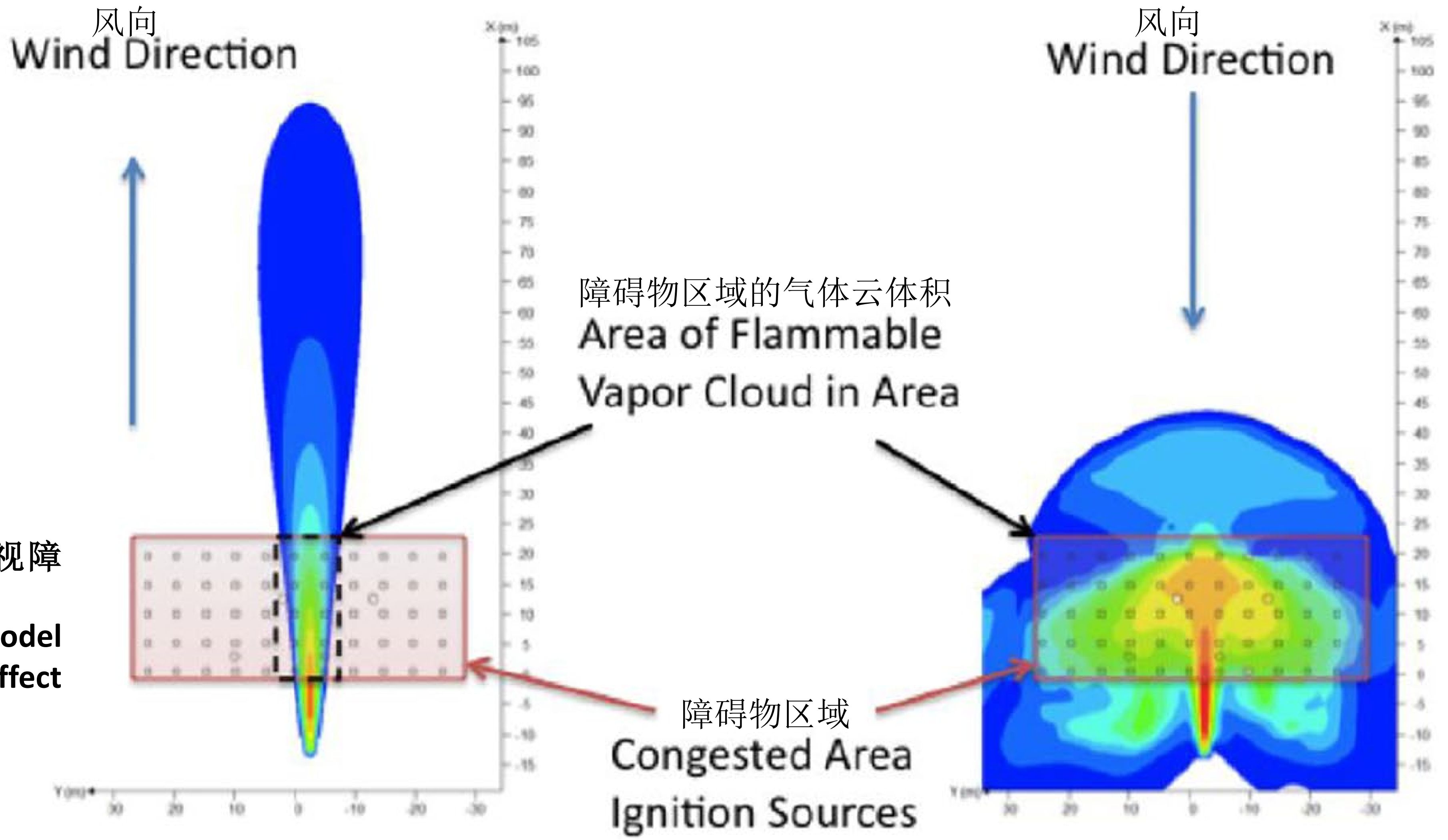
ISO 集装箱（Mock Urban Setting Test）

二维经验公式模型无法模拟这类场景

2D empirical formula model does not support this scenario

风向和几何障碍物对于扩散的影响

Effects of wind direction and geometry on dispersion



二维经验公式模型忽视障碍物屏障作用

2D empirical formula model neglects the barrier effect of obstacles

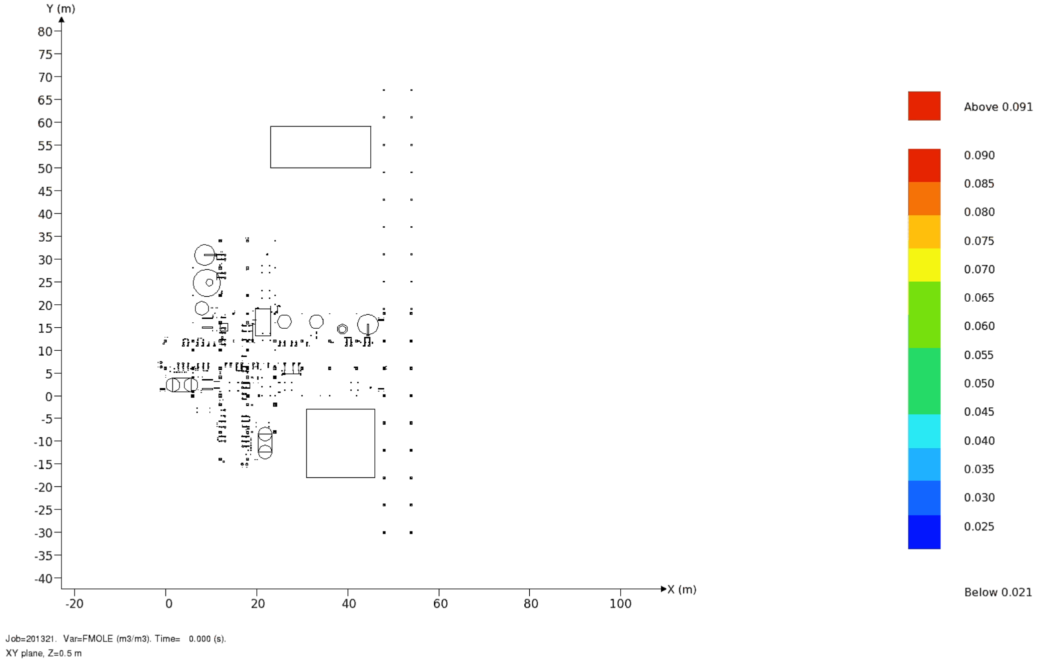
二维经验公式模型无法模拟这类场景

2D empirical formula model does not support this scenario

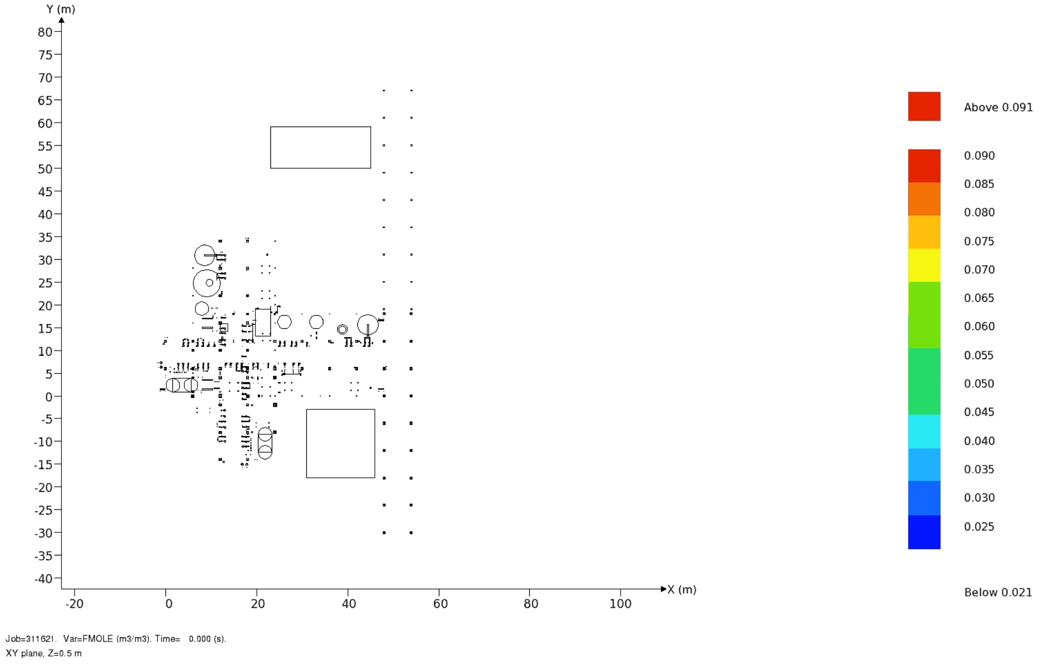
实际场景中的扩散

Dispersion in real scenarios

- 能精确预测泄漏和扩散，是确定爆炸负荷的前提必须条件
The ability to accurately predict leakage and diffusion is a prerequisite for determining the explosion load.

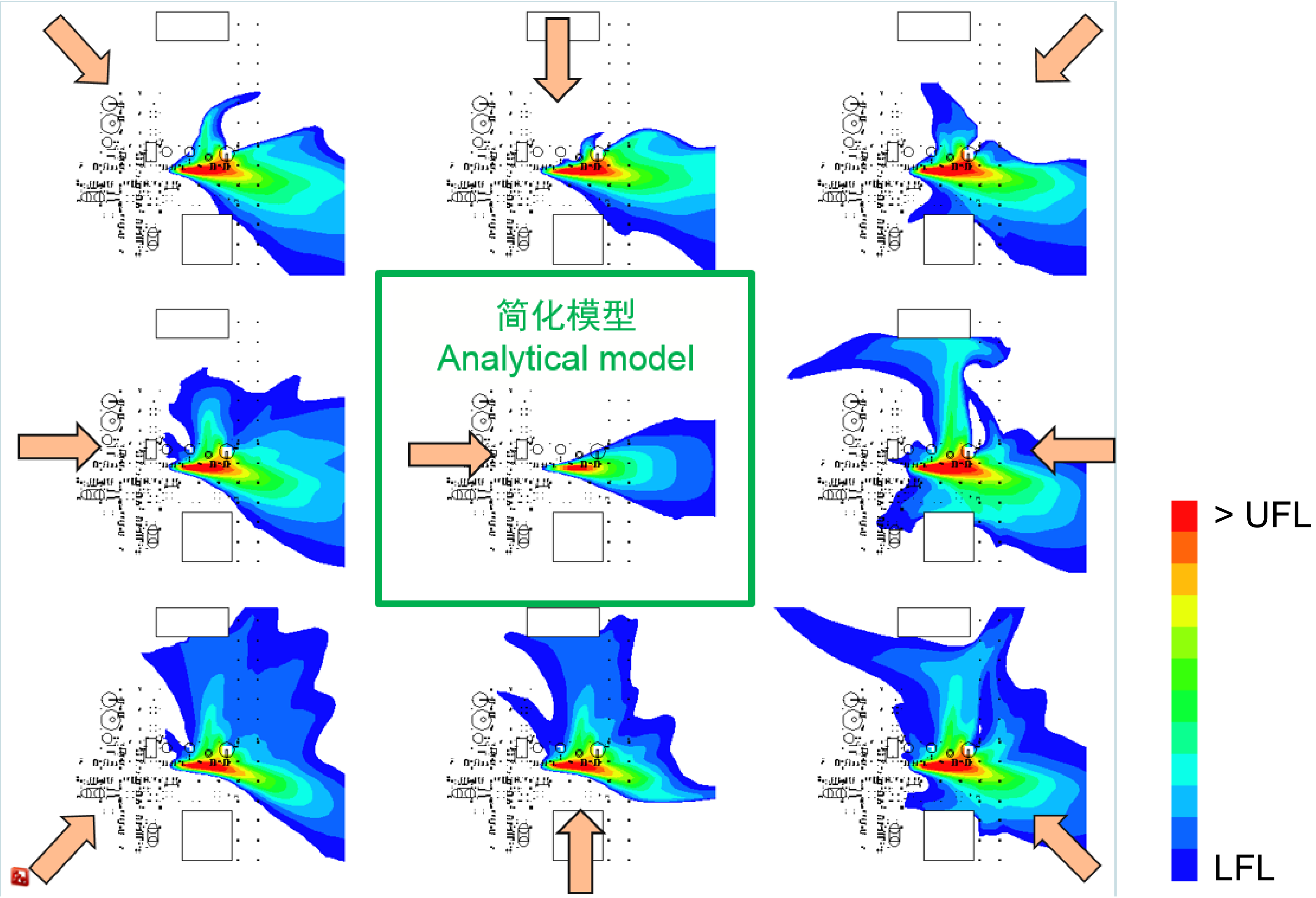


- 整合模型/ 简化工具，不能解释几何障碍物/地形对爆炸的影响
Integrated models/simplification tools do not account for the effects of geometric obstacles/terrain on explosions



丙烷泄漏(+X方向)

Propane leak (+X direction)



风速：2 m/s
Wind speed: 2 m/s

爆炸浓度气体云体积占障碍物区域的体积比
The ratio of the volume of the explosion concentration gas cloud to the volume of the obstacle area

Flammable volume (% of congested region)		
2.1	1.5	2.6
2.5	0.6	4.0
2.4	2.6	3.9

最不危险的工况
the least hazardous scenario

简化模型的泄漏与扩散缺陷

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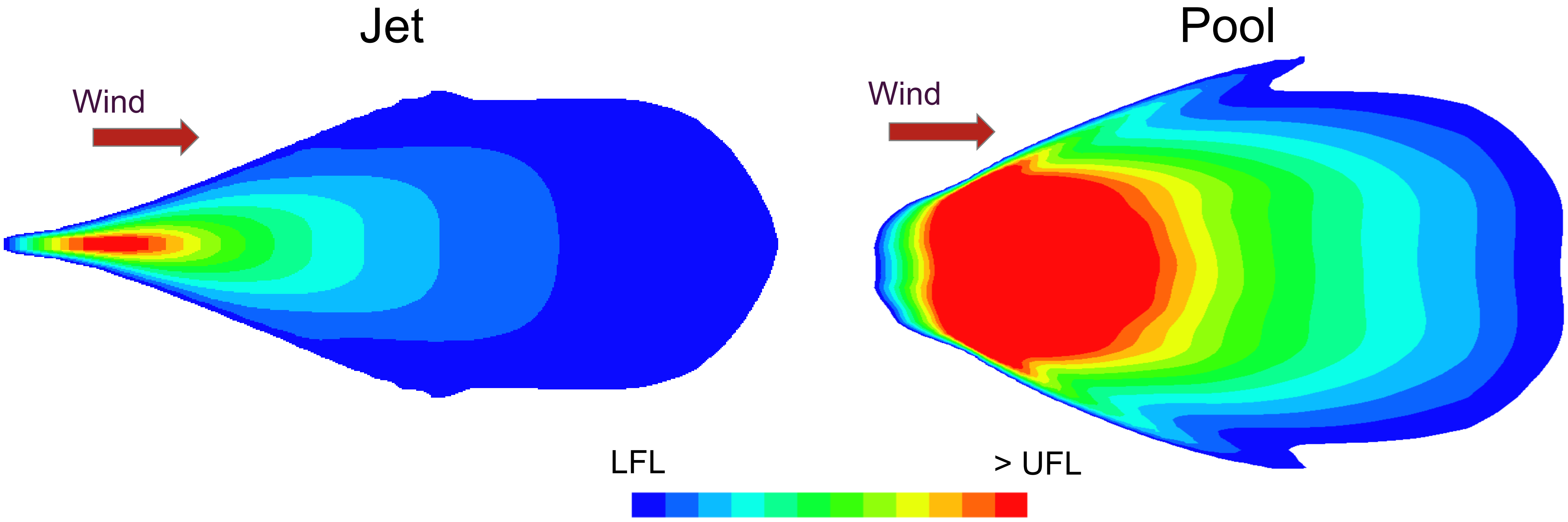
Leak and dispersion defects in simplified models

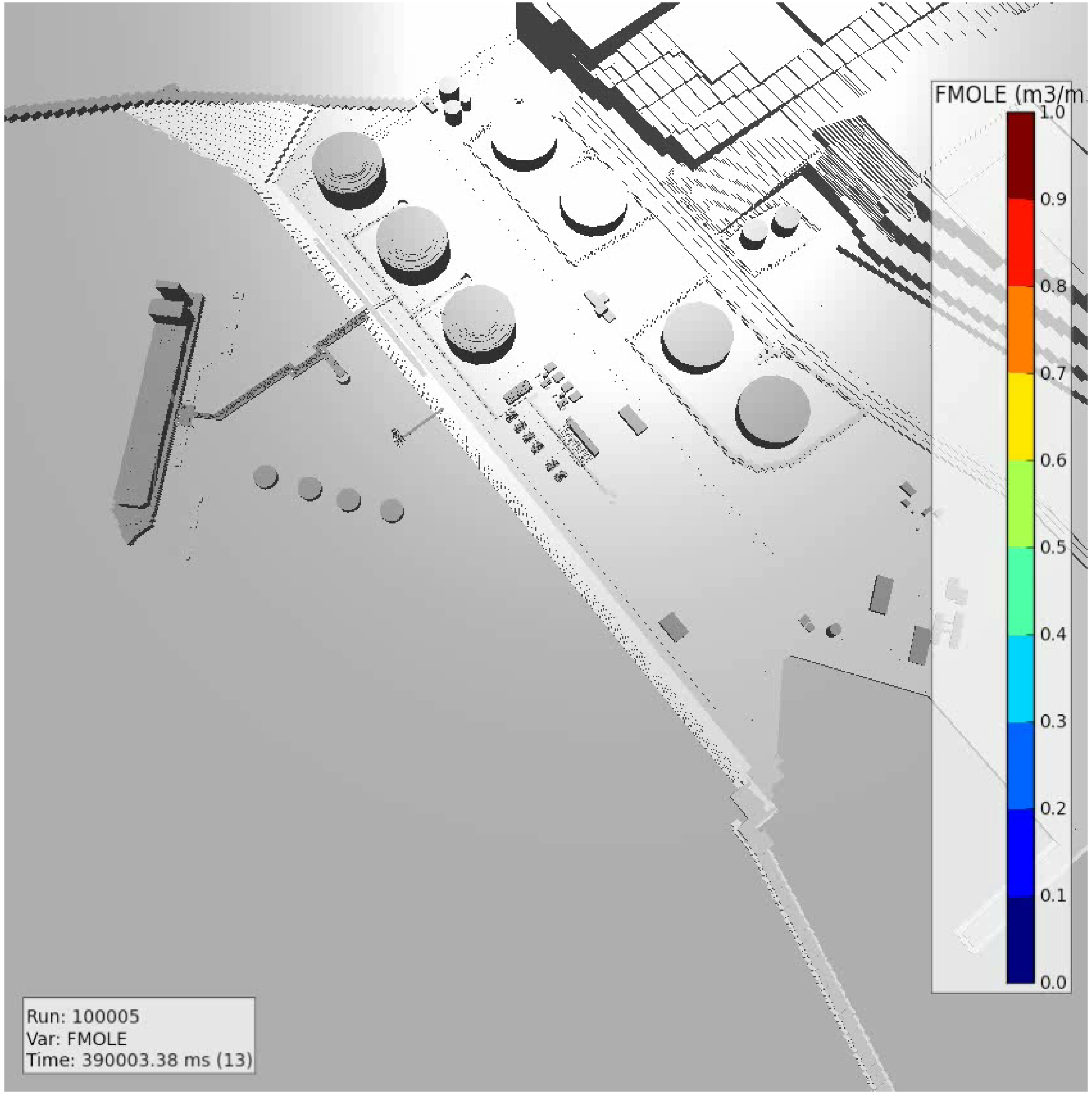
- 忽视障碍物和地形特征的影响 Ignore the effects of obstacles and terrain features
- 假设风向和泄漏方向同向(喷射) Assume that the wind direction is the same as the leakage direction (jet)
- 假设液体溢溅没有动量(液池) Assume that the liquid spill has no momentum (liquid pool)
- 假设泄漏位置周围的气体扩散呈现辐射对称状 Assume that the gas dispersion around the leak location is radially symmetric



LNG码头

LNG terminal

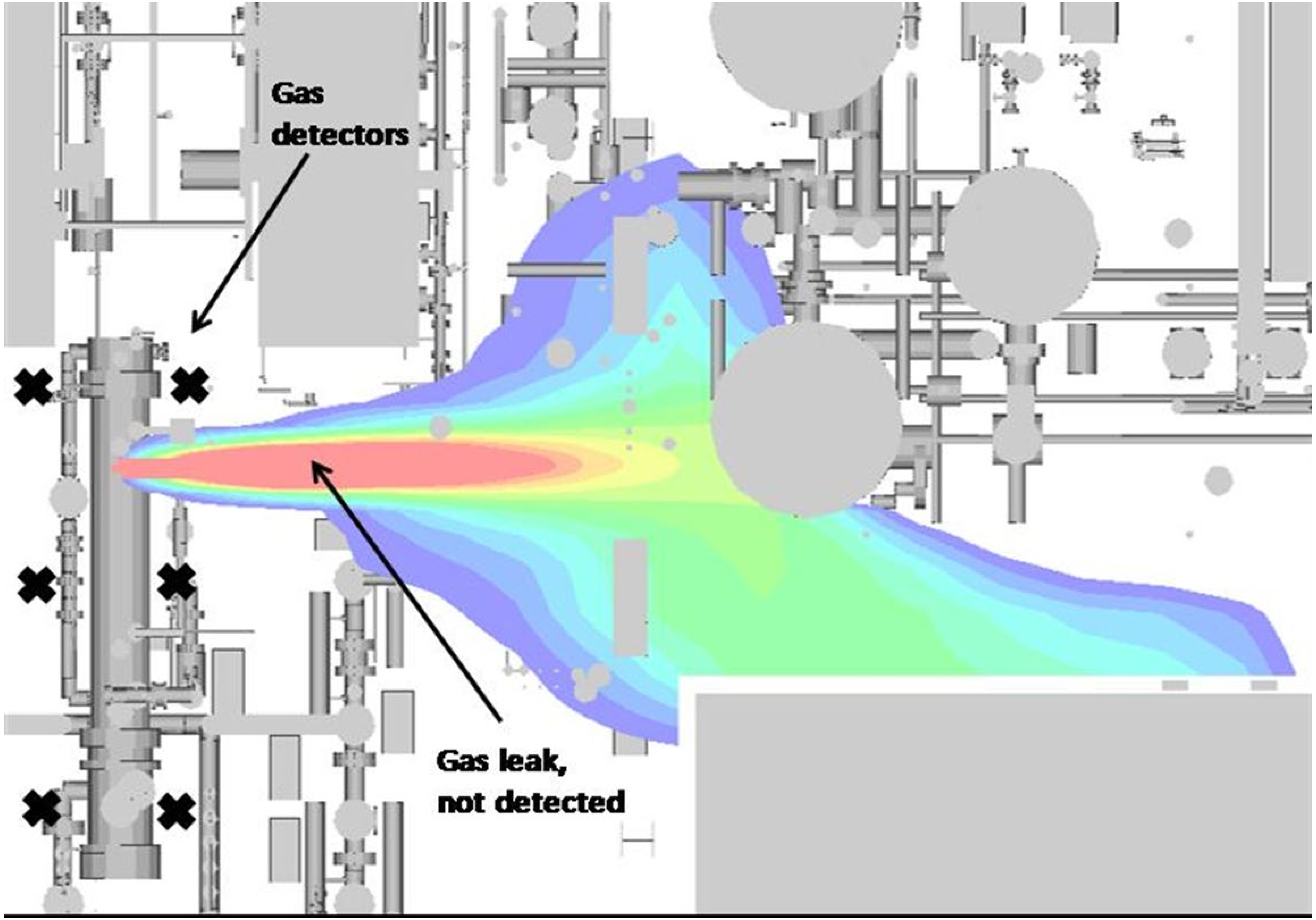
液化天然气在水面上扩散的过程
the dispersion of liquefied natural gas across the water surface



在潜在泄漏点附近布置的探测器不工作

Detectors placed near potential leaks are not working

等间距布置探测器的挑战
the challenges of placing detectors at equal intervals



简化模型分析爆炸的缺陷

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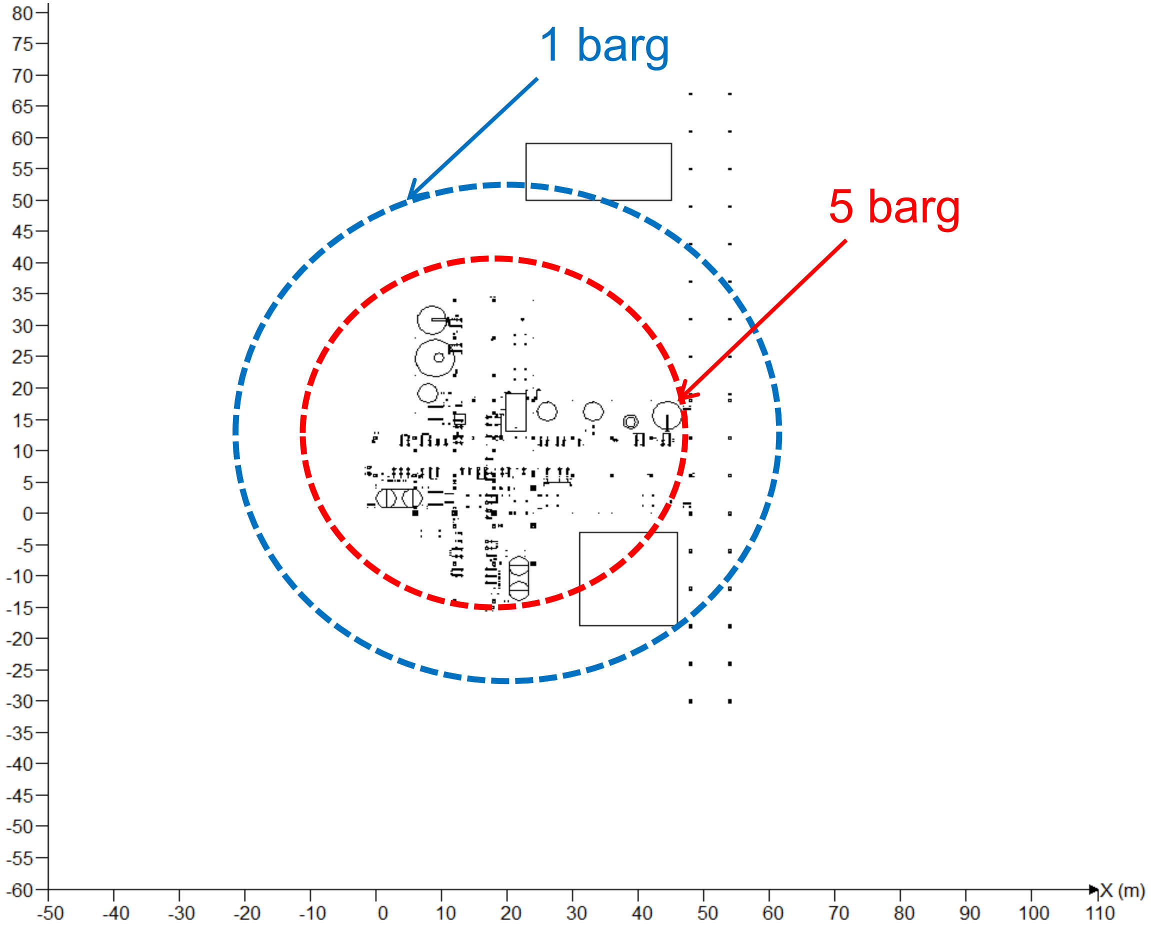
Simplified model analysis explosion defects

- 假设气体云中心附近障碍物的平均拥塞程度并呈对称分布
  Assume that the average congestion of obstacles near the center of the gas cloud is symmetrically distributed
- 假设最大火焰速度（基于燃料类型、气体云体积和障碍物拥塞度）
  Assumed maximum flame speed (based on fuel type, gas cloud volume, and obstacle congestion)
- 忽视遥远的障碍物对压力波累计的影响
  Ignore the effect of distant obstacles on pressure wave accumulation



FLACS气体爆炸模拟

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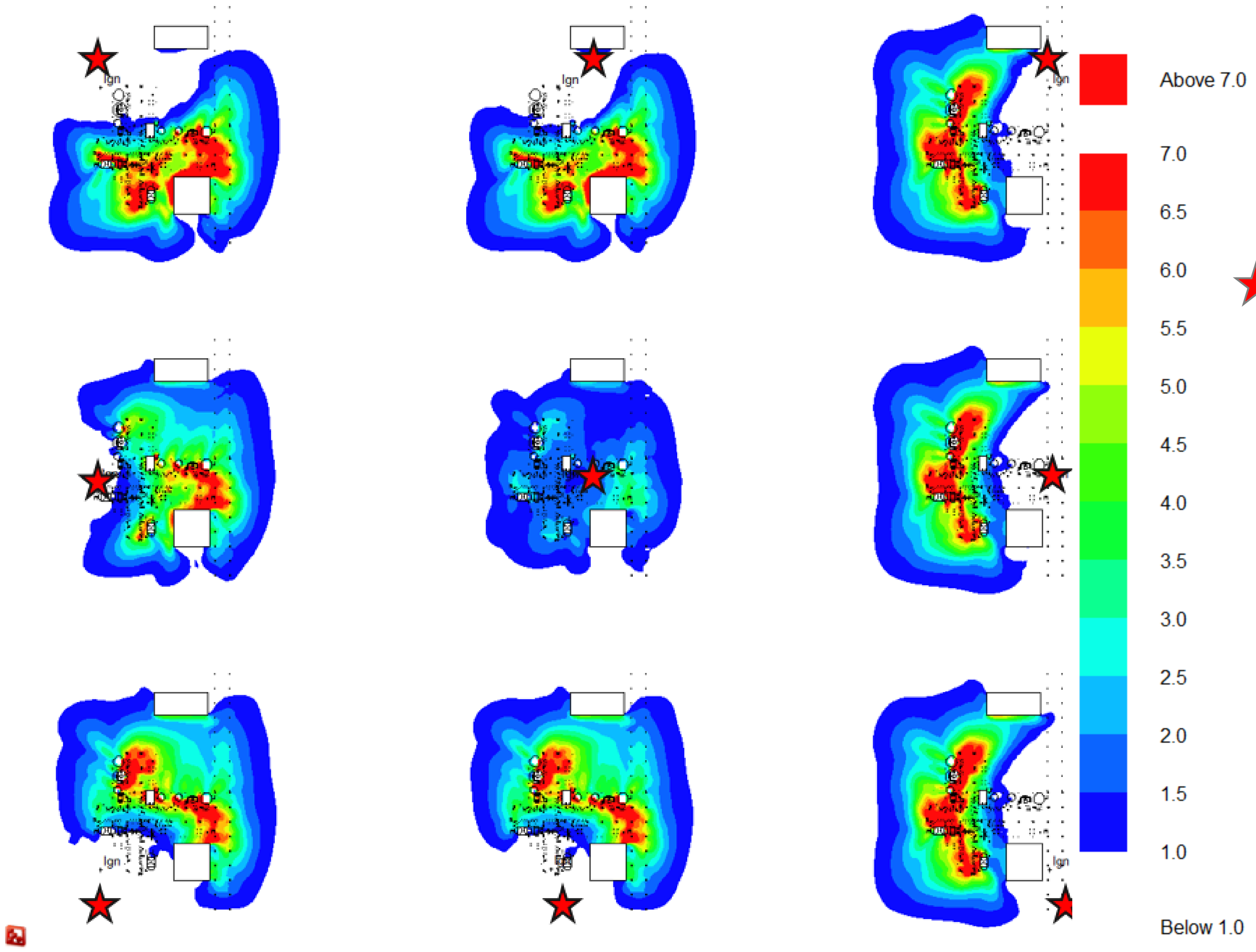
FLACS gas explosion simulation



★ =点燃点的位置

Location of ignition point

最大压强 Maximum Overpressures		
位于北部的建筑物 North building		
1.2	1.1	5.4
3.5	2.7	5.8
4.6	4.8	6.0
位于南部的建筑物 South building		
11.1	9.7	2.2
8.0	3.3	2.1
6.9	7.1	2.2

- 考虑实际的几何布局

Consider the actual geometric layout

- 计算局部火焰速度（火焰加速）

Calculation of local flame speed (flame acceleration)

- 考虑点燃位置和遥远的障碍物对压力波累计的影响

Consider the effects of ignition location and distant obstacles on pressure wave accumulation

简化工具和FLACS软件比较

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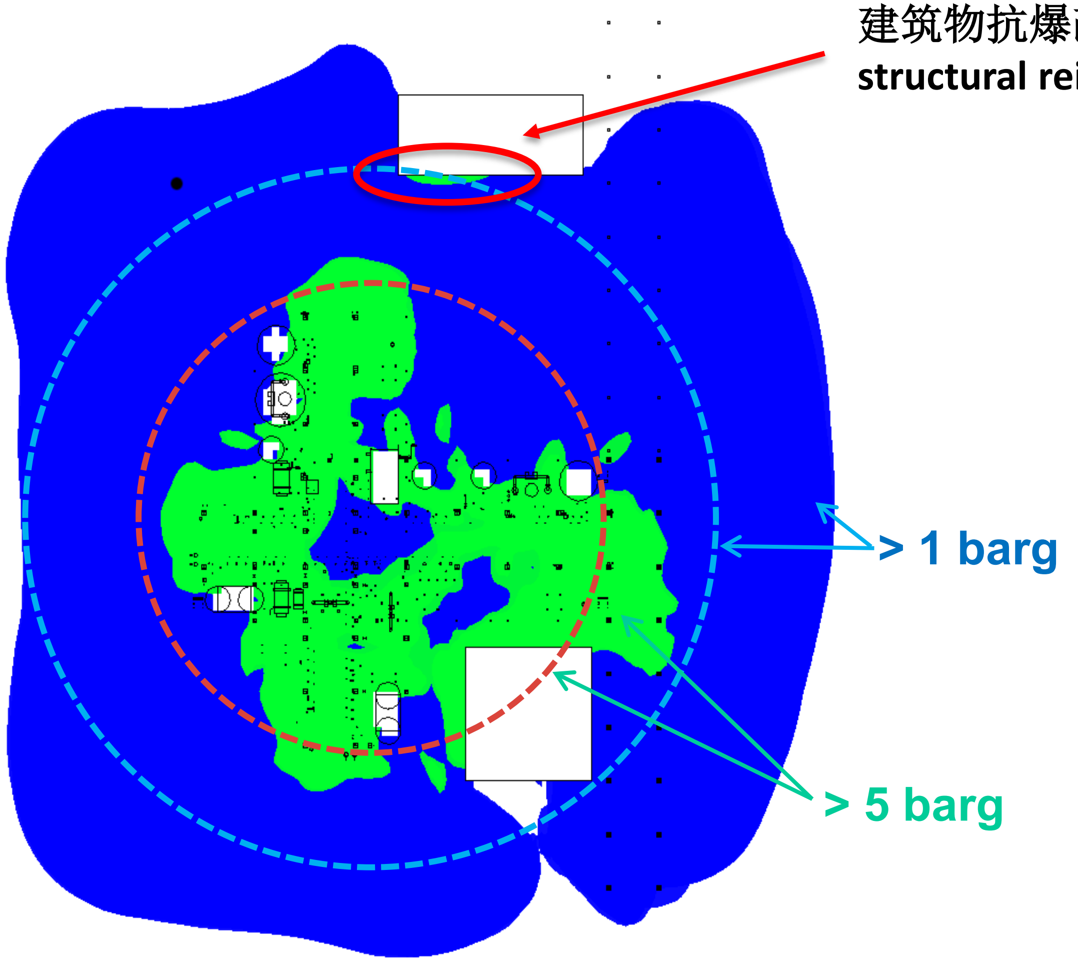
Comparison of simplified tools and FLACS software

最大超压分布的等值线图 Contour map of maximum overpressure distribution

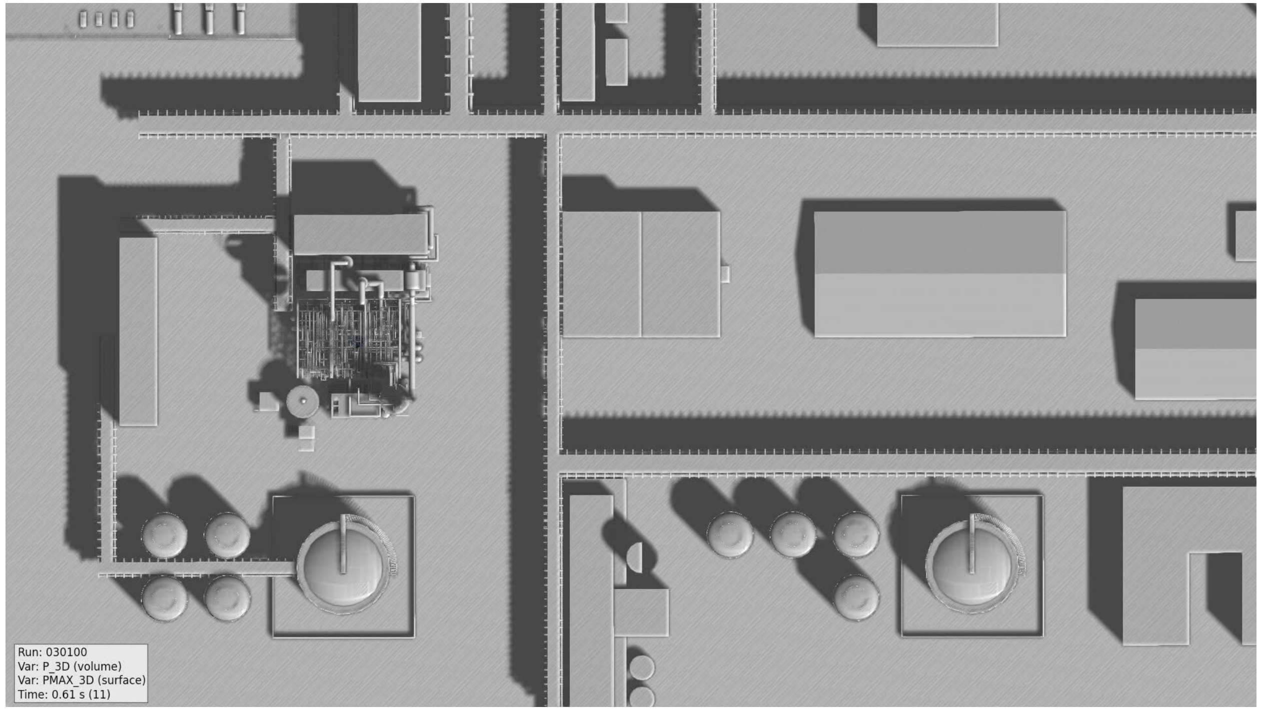


建筑物设计负荷（barg）
Building design load (barg)

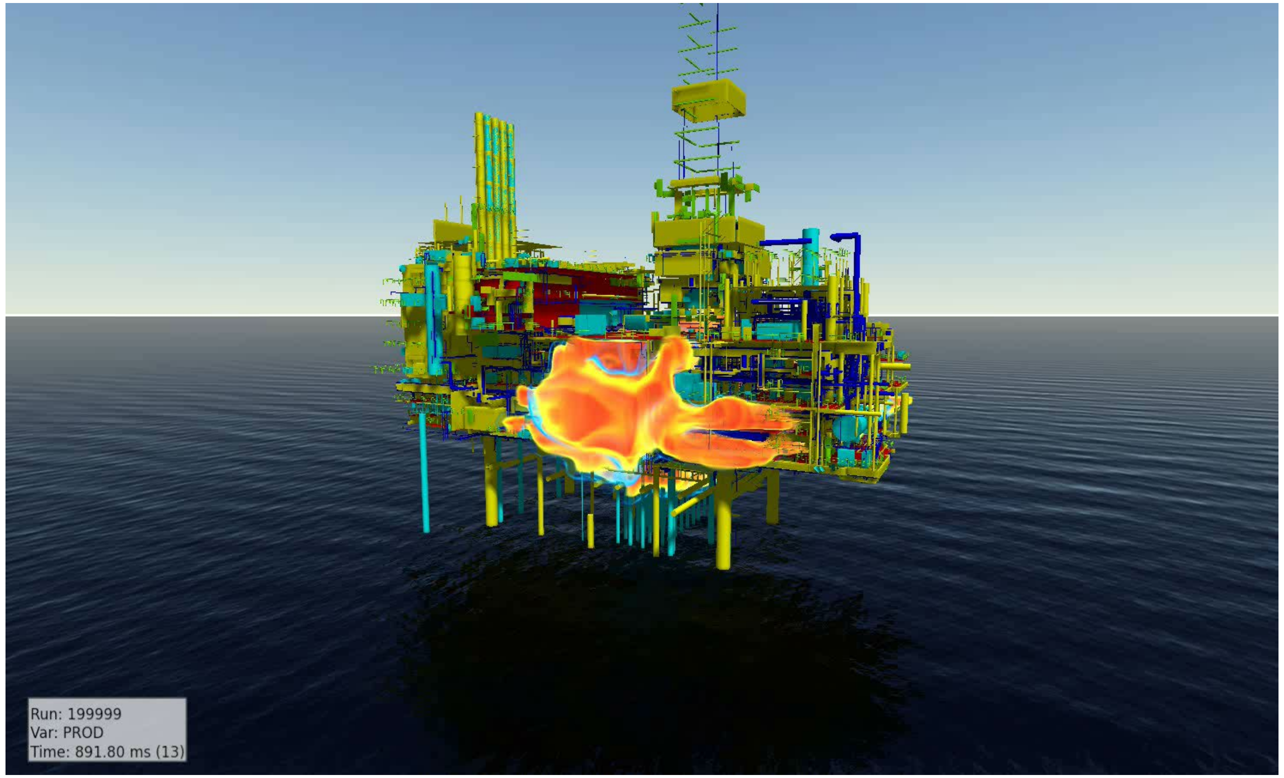
建筑物 building	简化模型 Simplified model	CFD模型 CFD Model
North	1.1	1.1 – 6.0
South	7.7	2.1 – 11.1

FLACS精确计算冲击波的反射

FLACS accurately calculates shock wave reflections



石油平台上的爆炸火焰
the flame propagation of an explosion on an oil platform



爆炸冲击波翻越建筑物后形成的负压和反射
the negative pressure region and shock reflections formed as the blast wave overtops the structure

混合使用

Hybrid use

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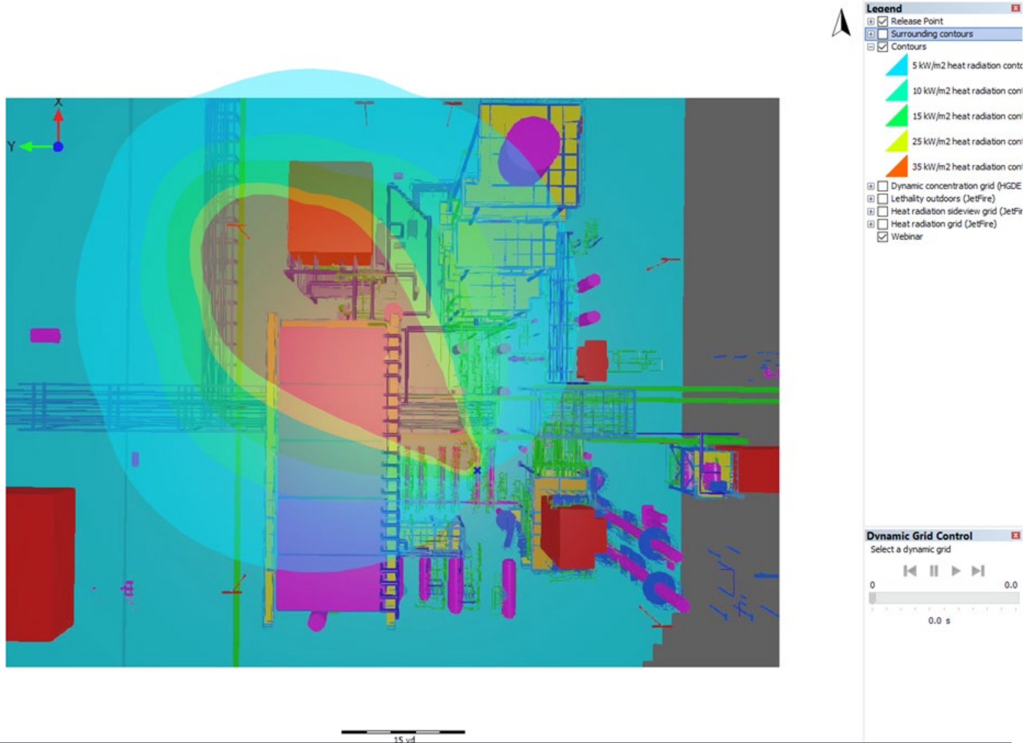
EFF FLACS

使用经验公式模型进行快速筛选，并使用 CFD 深入分析关键瓶颈。

Use empirical formula models for rapid screening and CFD for in-depth analysis of critical bottlenecks.

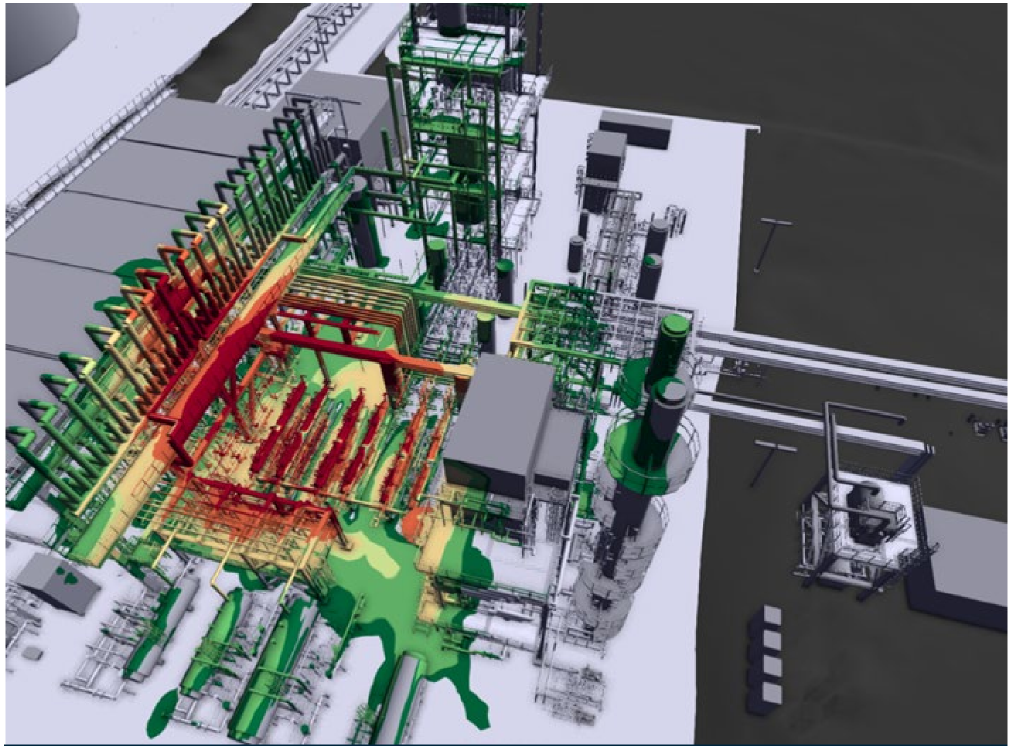
精准的风险评估能够优化空间利用，降低消防安全成本

Precise risk assessment enables space optimization and lowers fire safety expenses



喷射火辐射经验公式模型（3 kg/s 泄漏速率）
Jet Fire Radiation Empirical Formula Model (3 kg/s Leakage Rate)

经验公式模型强调应考虑热负荷过高的相邻其它装置
The empirical formula model emphasizes that other adjacent devices with excessively high heat loads should be considered.



喷射火辐射CFD模型（3 kg/s 泄漏速率）
Jet Fire Radiation CFD Model (3 kg/s Leakage Rate)

CFD 分析考虑了障碍物，并显示喷射火被阻挡和屏蔽CFD analysis takes obstacles into account and shows that the jet fire is blocked and shielded

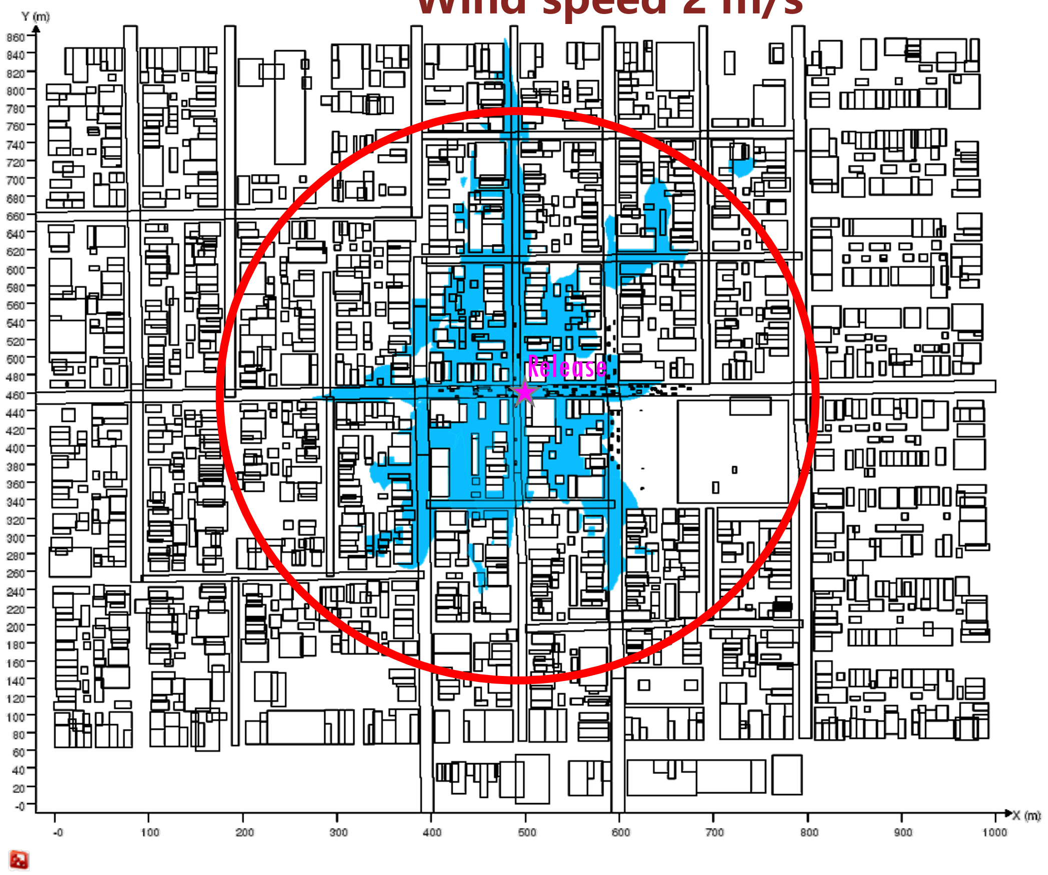
简化工具和FLACS软件比较：氨气泄漏距离

Comparison of Simplified Tools and FLACS Software: Ammonia Leak Distance

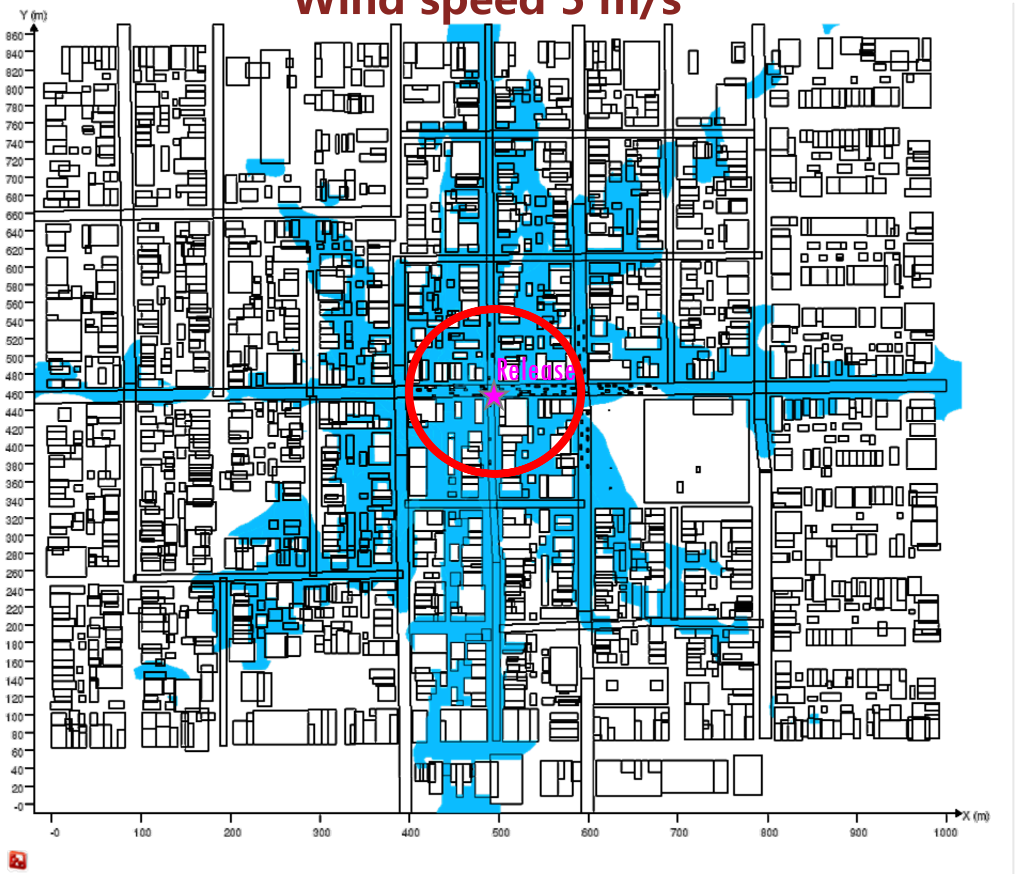
- 红色圆圈是简化工具分析的结果 The red circles are the results of the simplification tool analysis
- 蓝色区域是FLACS模拟的结果 The blue area is the result of FLACS simulation

➡ 简化工具得到的结果不一定保守 Results from simplified tools are not necessarily conservative

风速 2 m/s
Wind speed 2 m/s



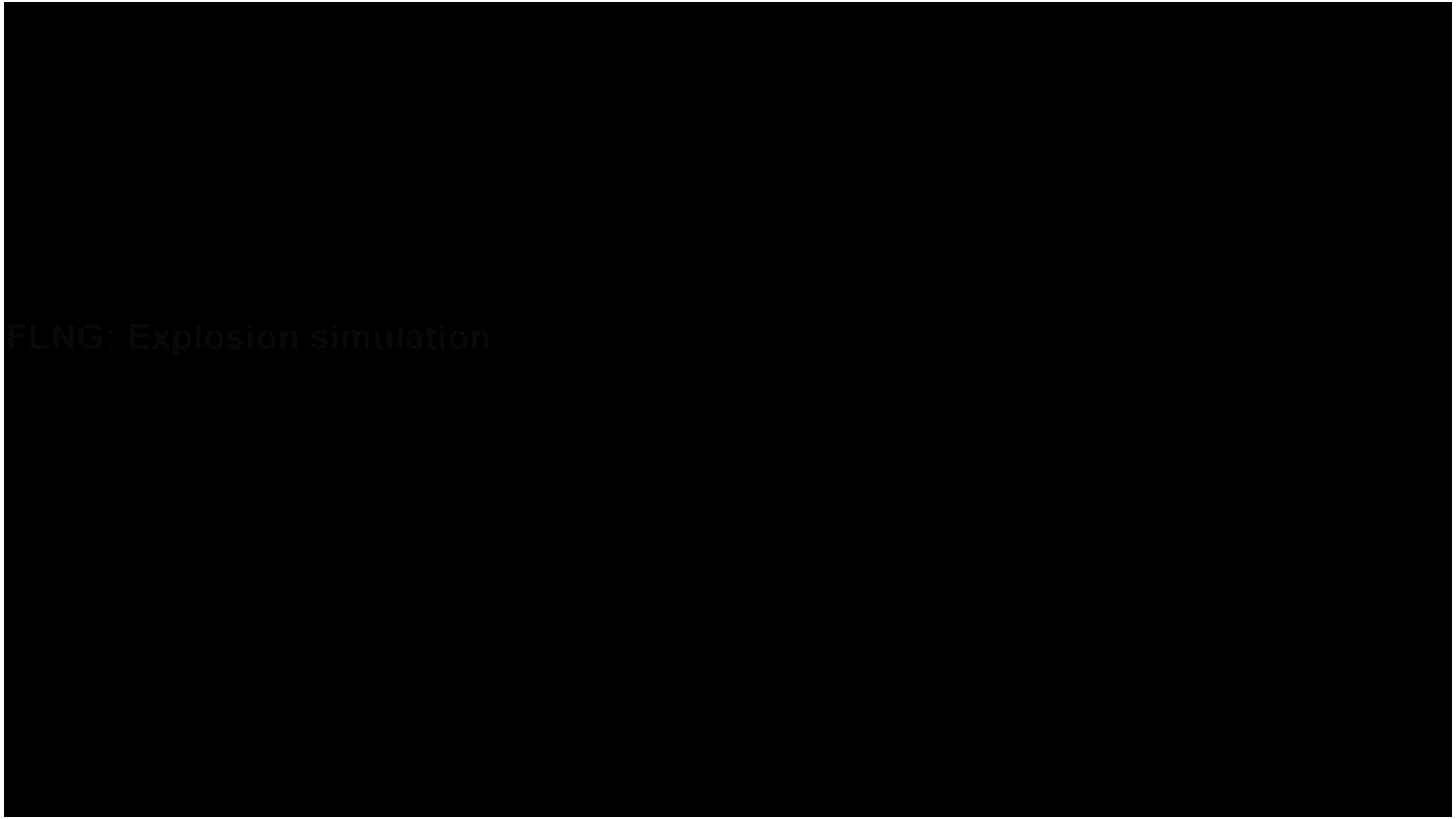
风速 5 m/s
Wind speed 5 m/s

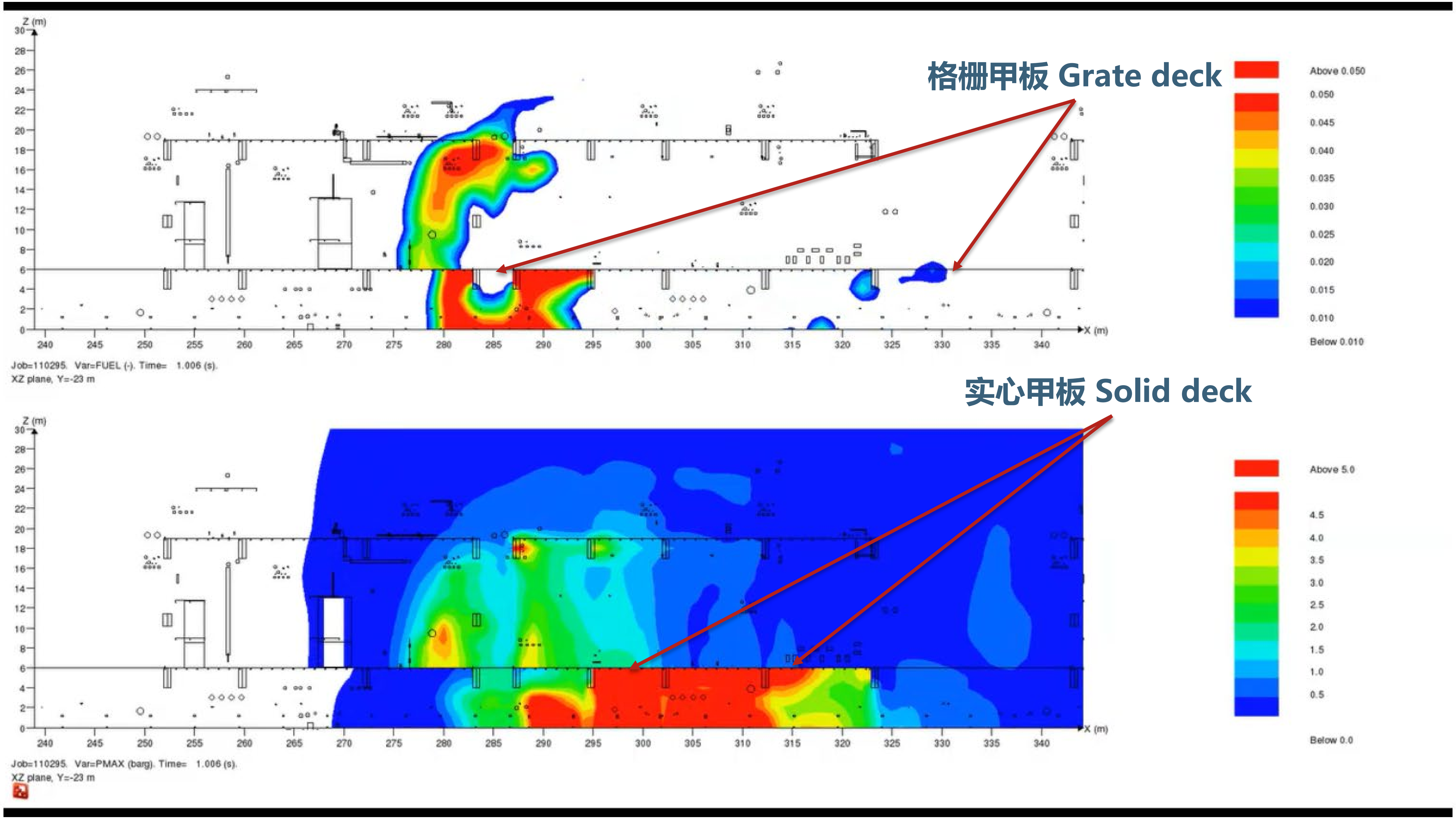


FLNG：爆炸模拟（混合制冷剂镀第一层甲板）

FLNG: Explosion simulation (Mixed Refrigerant, Plated First deck)

GEXCON

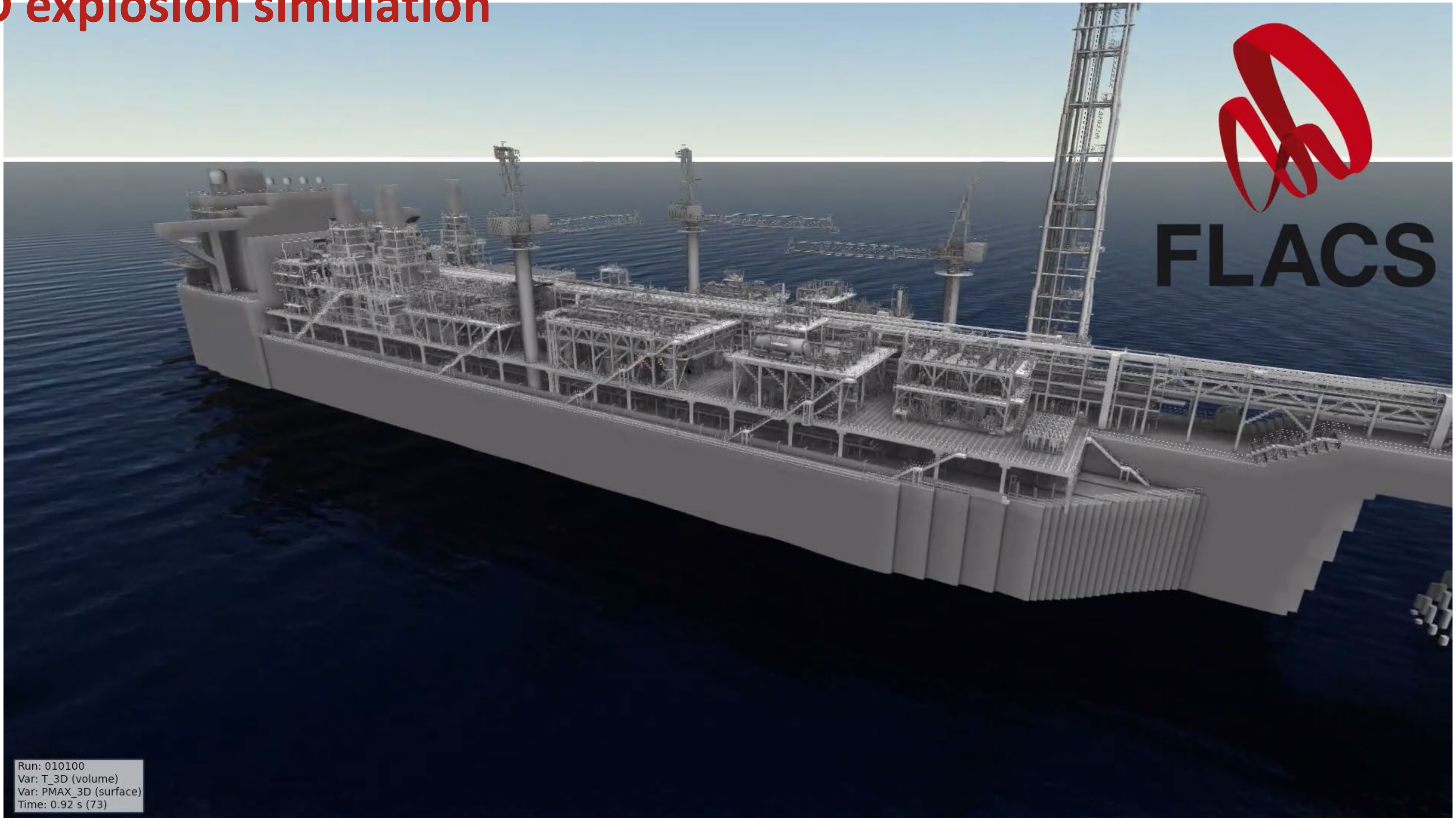




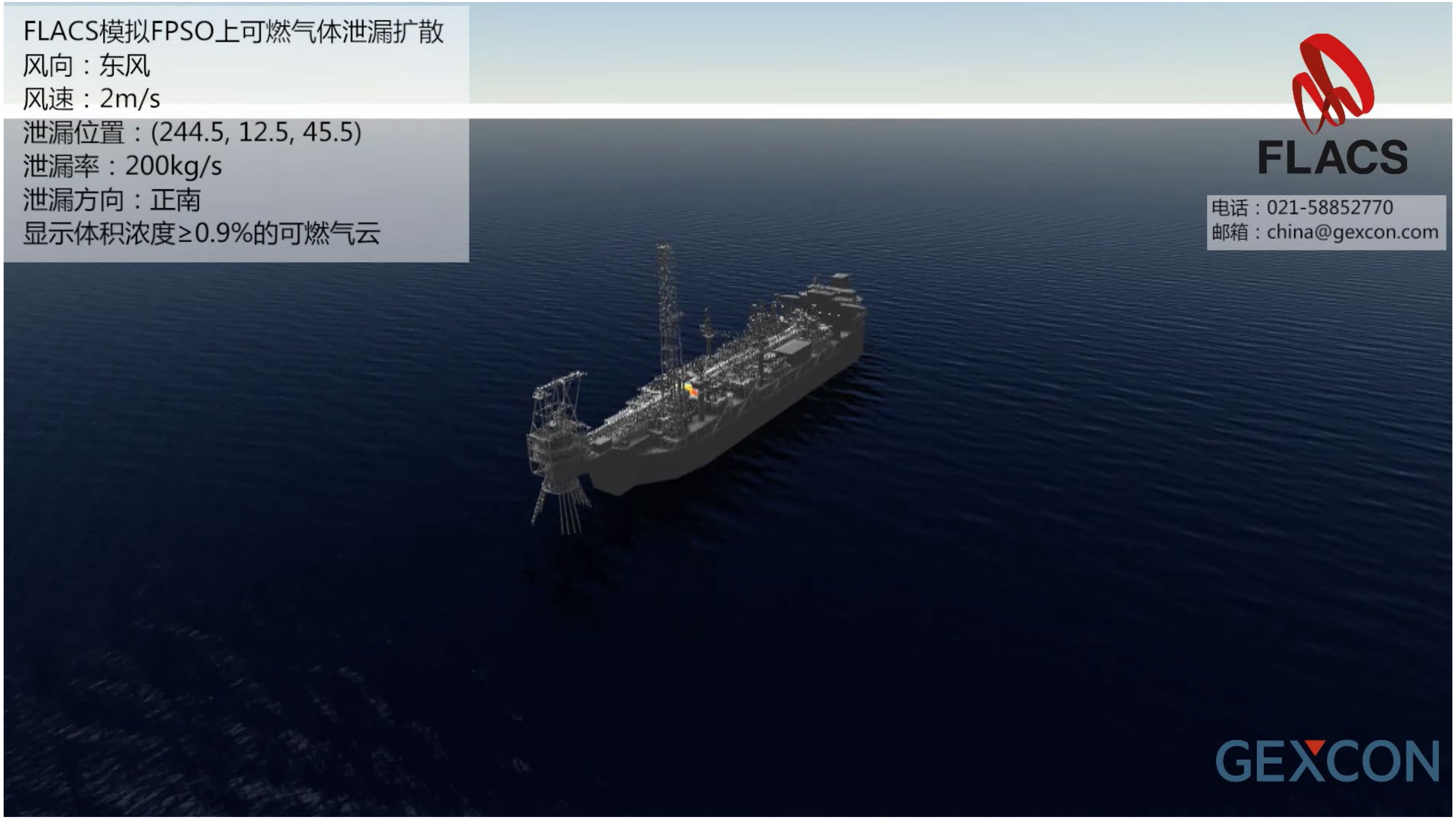
格栅甲板 Grate deck
实心甲板 Solid deck
Job=110295. Var=FUEL (-). Time= 1.006 (s).
XZ plane, Y=-23 m
Job=110295. Var=PMAX (barg). Time= 1.006 (s).
XZ plane, Y=-23 m
Above 0.050
Below 0.010
Above 5.0
Below 0.0

FPSO爆炸模拟

FPSO explosion simulation

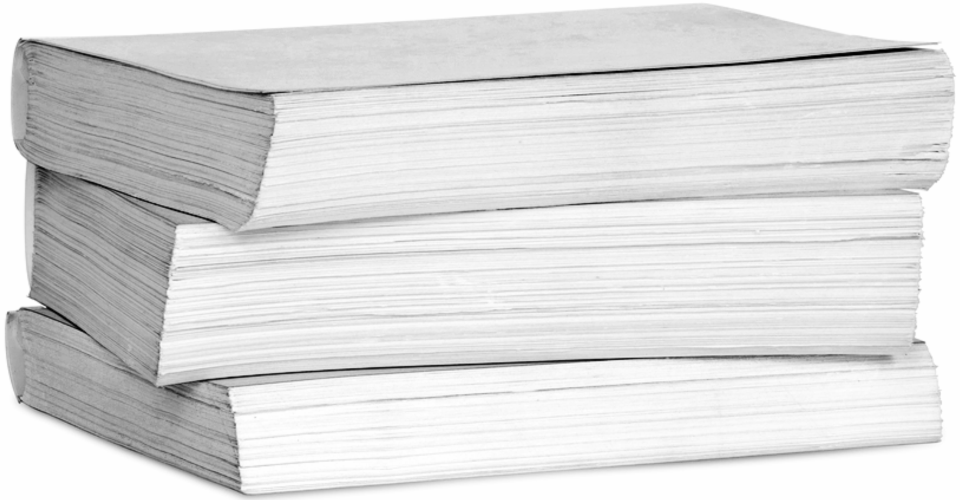


FPSO气体扩散模拟
FPSO gas dispersion simulation

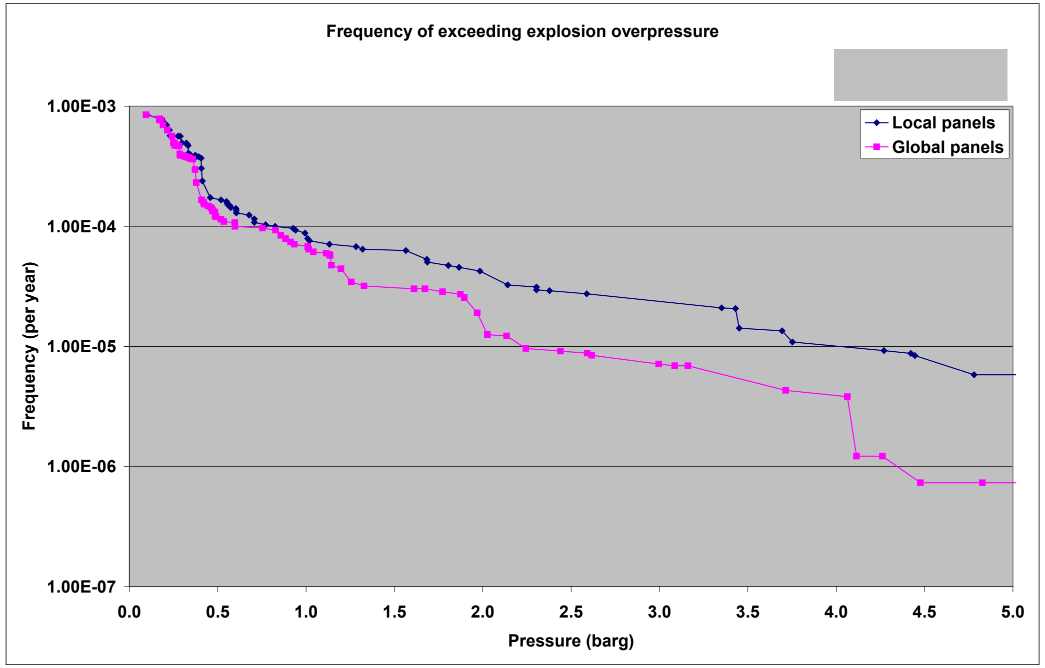


FPSO火灾模拟
FPSO fire simulation

动机
Motivation



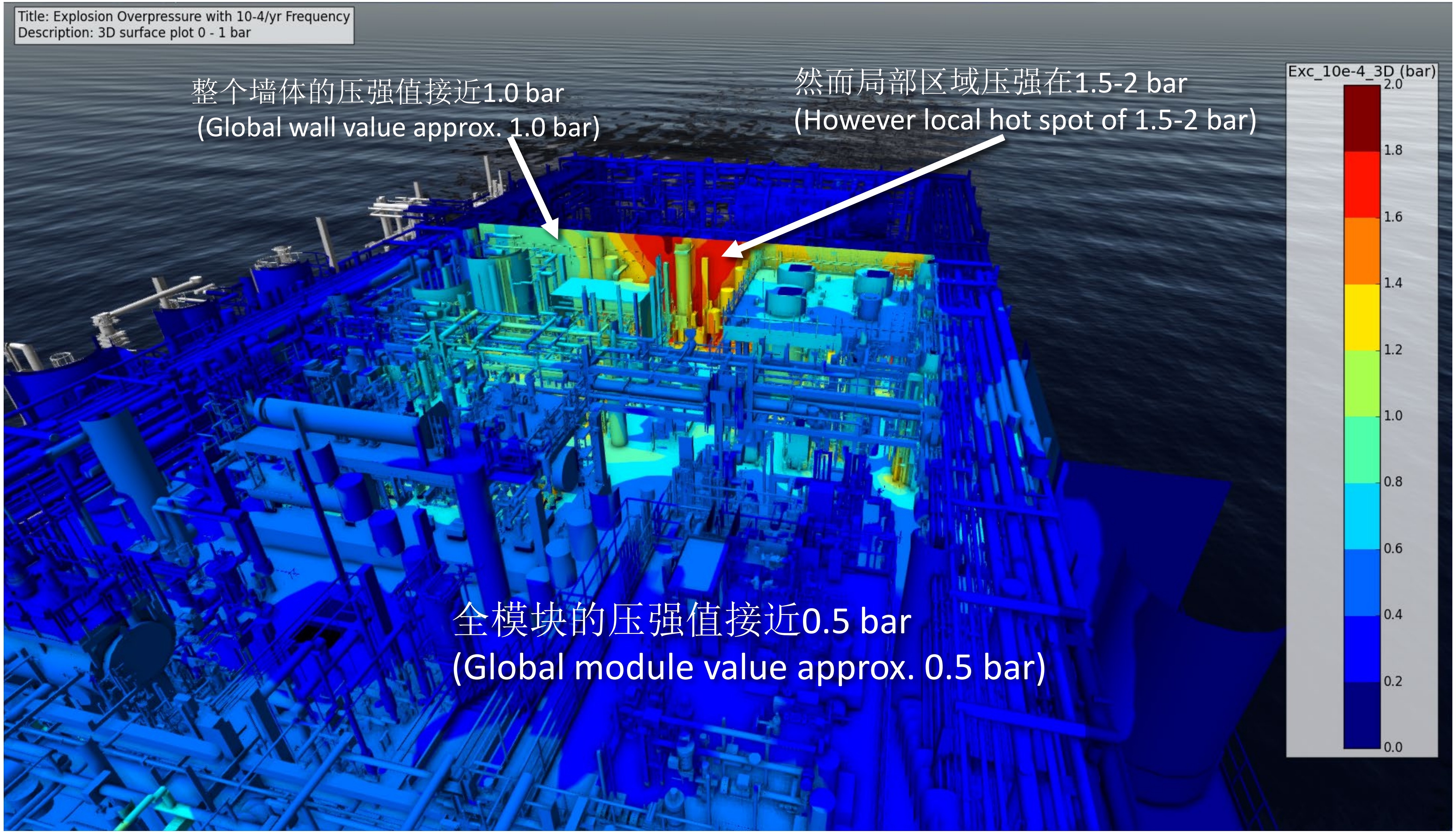
Object（物体）	Drag forces（阻力）[kPa] 10^{-4}/year	10^{-5}/year
Piping in Module M21（M21模块中的管道）	65	380



Traditional manner of reporting explosion study results
爆炸研究结果报告的传统形式

用新的三维可视化技术观察万年一遇的爆炸超压值

Observing the overpressure of a 10,000-year explosion using new 3D visualization technology



识别出高风险区域并协助判断是否值得采取措施降低风险

Identify high-risk zones and provide support in assessing the necessity of mitigation actions

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感谢聆听

Thanks

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